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A "PBL effect"? A longitudinal qualitative study of sustainability awareness and interest in PBL engineering students

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Abstract

The global sustainability crisis is growing by the year, and students are asking universities to increase sustainability contents in their curricula in response. The Education for Sustainability literature suggests that problem-based, interdisciplinary learning methods are well suited to imparting sustainability education. A recent quantitative study on engineering education supported this claim, showing that engineering students graduating from a systemic PBL university had increased sustainability awareness compared with graduates from other universities. But how does this awareness develop and manifest during the students' education, and what is the role of PBL therein? Answering this question requires a qualitative approach and therefore, we followed 16 PBL students across four engineering disciplines (mechanical engineering, electronic engineering, environmental planning and medialogy) during three semesters using semi-structured interviews and an interpretivist framework. We asked students to reflect on their awareness and interest in sustainability issues, in their first month of study, the end of their first year, and the middle of their second year. We were able to gauge the changes in their sustainability awareness and interest during the process of acclimatisation within their engineering studies.

We found that in the first round of interviews, the majority of students, with the expected exception of environmental planning students, were marginally aware of sustainability issues and not very interested in the subject. By the end of the study, a notable shift towards overall increased awareness and interest was observed. In this paper we use the interview data to explain and categorize the changes. The results underpin and qualify a discussion of the role of PBL in fostering changes in awareness and interest in sustainability.

Keywords: Sustainability Education, Engineering Education, Longitudinal Study, Qualitative Research, Problem-based learning.

Type of contribution: PBL research paper

1 Introduction

The United Nations Sustainable Development Goals (UNSDGs) aim to tackle some of the world's most "wicked" problems, including the climate crisis, plastic pollution, biodiversity loss, and chemical pollution in the air and water. These problems are such that some scientists warn us that we are currently pushing the limits of planetary boundaries beyond which human life of the planet would not be sustainable (Rockström, et al., 2009). The awareness of the multiple sustainability crises and the necessity to educate the workforce of tomorrow to actively contribute to resolving them has become an important goal for change in higher education. In engineering education, diverse strategies are applied to that effect, ranging from add-ons to existing courses, integration into a more coherent curriculum, and systemic curriculum change (Kolmos, Hadgraft & Holgaard, 2016)

Education for Sustainable Development (ESD) scholars have been suggesting for decades that pedagogies that foster collaborative problem-solving are a key component of *sustainable education* (Sterling 2001). In Engineering education, several scholars have argued that one of the best ways to increase sustainability awareness and engagement amongst engineering students is through group projects that are problem-based (PBL) (Coral, 2009; Guerra, 2014).

A recent longitudinal study of engineering schools in Denmark indicated that when students entered engineering studies nationwide in 2010, there were no significant differences between the students from different institutions with regards to any of the specific sustainability variables measured (Kolmos & Holgaard, 2017). These included self-reported "readiness" with regards to contemporary issues, ethics, the global context, the societal context, environmental impact and social responsibility. However, by the 10th semester, a significantly higher percentage of students from a systemic PBL university (compared to other universities) assessed themselves to be very well prepared for tackling sustainability issues, and had increased confidence in the above-mentioned sustainability competences (Kolmos, Holgaard and Clausen, 2020). All of the Danish institutions included in this study displayed elements of PBL within their curriculum. But only one institution had a systemic approach. This means that PBL was done at the level of the curriculum throughout the whole institution, rather than piecemeal in a course-by-course basis (AAU, 2020). This includes a more explicit progression throughout the curriculum for both sets of competences. Key to the findings of this study is that the observed increase in sustainability competences between entry into and exit from the study programmes is reinforced within a *systemic* PBLenvironment.

What is difficult to gauge from the quantitative data of this survey, however, is how exactly the sustainability competences develop from a similar baseline across all Danish engineering universities at the beginning, to marked differences in favour of the project PBL approach at the end. It is therefore necessary to take a magnifying glass to the experience of engineering students within the PBL system and find out how their awareness of and interest in sustainability evolve as they immerse themselves in their studies. Such an approach is best fulfilled through qualitative research methods in a longitudinal study, within the bounds of a carefully restricted time period to avoid losing the richness of the detail in overwhelming amounts of data.

As an exploratory approach, we suggest it would be interesting to look at the period in which students *acclimatise* to the PBL system throughout the first three semesters following the research question:

What are the patterns of change in students' awareness of and interest in sustainability issues during the process of acclimatisation to their engineering studies. Do we see differences across different engineering programmes?

2 Literature Review

2.1 Background

In this paper, we aim to present different patterns of change for students' development of sustainability awareness and interest during the process of acclimatisation within their engineering studies. This will help us to create a frame of reference for supporting engineering education for sustainability, and raises important concerns about the role of engineering education in the push for sustainable development. As noted by Svanström (2018:36):

> *First, it is perhaps important to mention the elephant in the room - should behavioural change be a goal of education? To discuss this, it first needs to be established what behaviour is considered. It is uncontroversial that we want students of engineering to adopt appropriate behaviour with regard to the profession and the different situations that may appear, for example to behave in a safe way in the laboratory and to behave towards collaborators and other people in an ethical manner. However, when it comes to the personal sphere, it might be considered controversial to aim for behavioural change, at least in higher education. Arguments against such approaches would be that they are normative and instrumental and that they therefore clash with ideals of 'Bildung' in universitystudies.*

In pointing to the "elephant in the room", this quote highlights the tension between the personal (private) and the social (public) formation processes within higher education, and the potential clashes that this creates between ideals of a more theoretically-oriented '*Bildung*' tradition on the one hand, and imperatives of behaviour change for sustainability on the other. It seems that, taking into consideration the urgency of addressing the sustainability crises, taming the elephant in the room might become a question of redefining the ideal of '*Bildung*'.

Lange (2004) suggests that one way to do this is through the use of dialectics, in particular through the importance of a dialectic relationship between transformative and restorative learning. He argues that these two types of learning together constitute the pedagogical basis for sustainability education, which can revitalise citizen action. Whereas restorative learning adds stability by providing insights into, or at least interpretations of, dominant cultural scripts; critical transformative learning attempts to foster an individual's consciousness of himself or herself as situated within a larger societal context. Therefore, adding sustainability perspectives to an engineering curriculum not only adds introspection into one's own role in sustainable development, it also increases the complexity of one's social sphere.

To address this complexity, several scholars in engineering education for sustainability have called for system-thinking (e.g. Dowling et al., 2009) and trans-disciplinarity (e.g. Byrne & Mullally, 2016). In engineering education for sustainability, this is related to the increasingly distributed innovation process, the increasing complexity of technological systems as well as the complexity of the sustainability challenge as outlined by the UNSDGs (UNESCO, 2017).

2.2 Sustainability competences and engineering education

A recent UNESCO report (Riekman, 2017) emphasizes new types of sustainability competences cutting across the SDGs as an important learning outcome for students to achieve:

1. System-thinking, critical thinking and strategic competences which are based on knowledge of the field;
2. Integrated problem-solving and collaboration competences which are based on knowledge and skills.

3. Anticipatory, normative, and self-awareness competences which are all competences based on a combination of knowledge, skills and personal awareness.

According to the US accreditation unit for engineering programmes, ABET, engineering students need "*the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context*" (ABET, 2017: 5).

Based on a comprehensive study of 10 engineering education institutions, Coral (2009) concludes that problem-solving prepares students to be responsible, which is likely to require introspection about their values, ethics and beliefs. Furthermore, Coral (2009) concludes that project-based learning linked to real transdisciplinary projects is the most adequate pedagogy to learn sustainability competences. Other studies (e.g. Guerra, 2014) conclude in a comparable way that problem and project based learning can be seen as a promising strategy in terms of embracing the personal (introspection, responsibility, agency – linked to competency 3 above) as well as the social (distributed, real-world, transdisciplinary – linked to competences 1 & 2 above) aspects of sustainability.

Taking the above into consideration, we aim to broaden the study of students' awareness and interest to work from the assumption that the dialectic relationship between the personal (private) and the social (public) spheres play an important role in defining patterns of change in students' awareness and interest. Furthermore, as problem and project based learning is highlighted as a promising approach for education for sustainability, we will study these patterns of change in an institutional case founded on this approach.

3 Methodology

Given the existence of prior quantitative surveys on the subject, this paper use a qualitative *thematic analysis* approach (Braun & Clarke, 2012), characterised by relatively small sample sizes (between 10 – 30 participants), rich data analysis and a focus on transferability rather than generalizability. Given how little has been written on the subject, we chose an inductivist approach to theme construction rather than a theory-driven one, meaning that the themes emerge from the data rather than from a pre-determined theoretical framework. We operate within a social-constructivist epistemology, meaning that we are not looking for "objective" descriptions of social phenomena with *essential* qualities, but for the ways in which participants *construct* meanings and understand their place within social phenomena whose interpretation is subjective to participants and researchers alike (Bailey & Douglas, 2014).

3.1 Participants

As with most qualitative studies, we used purposive sampling to gather participants (Etikan, 2016). We specifically looked for participants from three different types of engineering studies: "classical" engineering, for which we contacted students from electronic engineering and mechanical engineering, tech-oriented engineering, for which we contacted students in a computer science and design programme called *medialogy*, and more "soft" sustainability-oriented engineering, for which we contacted the students from a planning programme in environmental management (BEM). Within those categories, we recruited male and female participants, in proportions which reflect roughly the proportions within the student population. We therefore had only had one female participant in the "classical" engineering category, one in the "tech-engineering" category, whereas the majority of the participants in the BEM programme were female. We were looking to recruit between 7-10 participants in each engineering programme, but due to the time-consuming nature of qualitative interviews, 6 participants signed up in each programme, and two dropped out in between the first and second interview in mechanical engineering and BEM, bringing the total number of participants to 16 over the entire study.

Table 1: Participants in the longitudinal sustainability study.

Grouped per engineering degree programme			
Student	Age (at the start)	Gender	Degree Programme
EE.1F	19	Female	Electronic Engineering
EE.2M	33	Male	Electronic Engineering
EE.3M	23	Male	Electronic Engineering
ME.1M	32	Male	Mechanical Engineering
ME.2M	29	Male	Mechanical Engineering
ML.1M	19	Male	Medialogy
ML.2.F	22	Female	Medialogy
ML.3M	20	Male	Medialogy
ML.4M	22	Male	Medialogy
ML.5M	19	Male	Medialogy
ML.6M	19	Male	Medialogy
BEM.1F	21	Female	Bachelor Environmental Management
BEM.2M	18	Male	Bachelor Environmental Management
BEM.3F	21	Female	Bachelor Environmental Management
BEM.4F	20	Female	Bachelor Environmental Management
BEM.5F	22	Female	Bachelor Environmental Management

3.2 Interviews

The participants were informed by email of what the study was about, provided with a slide deck explaining the purpose of the study, the number of interviews they were expected to attend, the approximate duration of the interviews, and how the data would be handled. They were asked for their consent to record the interview and use the data anonymously for research purposes before each interview, and agreed on record. There were three rounds of interviews: one round at the beginning of the bachelor programme during the introductory PBL project period known as P0, one round after students completed their first fully fledged project, in the beginning of the PBL project period known as P2, and a final round at the end of P3, by which point students are considered to be “acclimatised” to their PBL studies. The questions of the final round were sent in advance to the students to provide them with some time for reflection. We noted that this increased the quality of the answers.

Table 2: Interview rounds and structure

Interview Round	Interview Structure	Question themes
R1 (Start P0)	Semi-structured, same structure for all students. Questions not sent in advance.	Personal history; Reasons for choosing engineering; Sustainability awareness and interest; Sustainability actions
R2 (Start P2)	Unstructured, following on from answers from R1. Questions not sent in advance.	Students asked to reflect on previous responses, and anonymous responses of others.
R3 (End P3)	Semi-structured, but structure is personalised for each student	Sustainability awareness and interest [If increased, reasons for increase] Sustainability actions

	based on previous answers. Questions sent in advance.	[Reasons behind (in)actions] Reflections on relationship between students' specific field of engineering and sustainability Future perspectives on sustainability

3.3 Analysis

Unlike phenomenological or phenomenographic work, thematic analysis does not require verbatim transcripts, so the researchers listened through the audio recordings of the interviews several times. The first time, no notes were taken so that a full picture could form in the researchers' head. The second time, the researchers noted down all the key points and interesting quotes in the interviews, then transferred this into a spreadsheet in a 3 x 16 matrix where all of the interview notes could be compared across participants, and across the rounds of interviews. The interview notes where then organised thematically in response to the research question. We classified the student responses into four thematic categories that form "levels" of awareness and interest.

4 Data Analysis

If we define awareness as *knowledge and understanding* of the sustainability crises, and interest as *the propensity to seek out information about the sustainability crises*, we see that students fall into four basic categories of awareness and interest.

4.1 Category 1: no interest, little general awareness

The first category indicates that students express no interest and very little knowledge or understanding of sustainability issues. For instance, **ML.6M** said:

> ***ML.6M R2:*** *I know it's a thing, but I don't know what to do about it… well, it's partly my own fault because I haven't looked up what I could do about it, but I don't know, if the world… this global warming, I don't know what I could do to help… ignorance is bliss.*

There were three rationales offered for this lack of interest and awareness, the first, as exemplified by ML.4M, is that the sustainability crisis is too frightening and calls upon such changes in attitudes and behaviours that it is better not to know and not to deal with it:

> ***ML.4M R1***: *I think we did a project once [in high school] about some environmental stuff, and it was scary… [it made me feel] sad and worried, I'm afraid for the next generation.*

The second, as exemplified by ML.2F, is that the students are devoting so much cognitive bandwidth to their studies that they don't have time or energy to get informed about sustainabilityissues:

> ***ML.2F R2***: *I think I'm much less considerate to things happening outside my studies because it takes up all the space.*

The third, shown by EE.3M, is that personal issues mean that the students are more focused on their immediate worries than about global problems:

> ***EE.3M R1:*** *I don't really know what I would do if, like, my house was submerged in water and things. I mean it's not really things that I worry about daily. I have other things to worry about, like how do I survive the end of the month.*

The fourth is that in the absence of obvious strategies to solve the sustainability problem, students would prefer not to know too much or worry too much about it, as exemplified by **ME.1M**:

> ***ME.1M R1:*** *I, pfff, I haven't really given it much thought, and I don't… I try not to interfere with stuff that's out of my reach.*

4.2 Category 2: little interest, basic general awareness

The second category indicates that students show a little bit of interest in sustainability issues, usually triggered by postings on social media, and are curious enough to read up on the basics, as such being aware of issues like the climate crisis and plastic pollution, some of the basic drivers of those issues like eating meat, flying, consumption culture etc., and that these issues are getting worse. However, this basic knowledge often seems to trigger feelings of cognitive dissonance that comes with this basic knowledge, as exemplified by **ML.3M:**

> ***ML.3M R2*****:** *I know about the effects that the meat industry has on a global scale, but I would never really consider becoming a vegetarian because I like the taste of meat... I think it's part of a healthy diet and all the like, and perhaps it's also a bit of… you kind of feel entitled to that, after this many years of evolution, we have climbed our way to the top of the food chain, we have opposable thumbs, we deserve to eat meat.*

Cognitive dissonance can be defined as an attempt to reconcile incompatible beliefs and actions, and is a common reaction to increased sustainability awareness (Stoll-Kleeman et al, 2001) In this case, believing the meat industry is a sustainability problem, but continuing to eat meat. As shown in this quote, one strategy to resolve cognitive dissonance is to provide mitigation to the belief system to make it "fit" with the actions – in this instance, a moral justification for eating meat, "we deserve it". Another reaction to this level of basic awareness is conflicted emotional feelings, and technological escapism – the idea that we can escape to Mars was particularly prominent in the medialogy and classical engineering groups, as exemplified by**EE.1F**:

> ***EE.1F R2****: I've been in this denial thing, "oh this will affect my children, my grandchildren", but then I've learned that it is happening now so it is affecting me, so I've gone to "I sort my plastic, I sort the waste and I don't use plastic straws and all that stuff". It's not enough to make it OK. Just because I do it. So, I'm also a bit in despair, well, we're kinda screwed, let's go to Mars!*

4.3 Category 3: basic interest, basic general awareness and advanced domain-specific awareness

The third category shows that students have a basic interest in sustainability issues, meaning that they are sufficiently driven by the issue to read news on the subject, to pick up on the issue when it is raised in their studies, and to involve the issue in their PBL projects. As such, while they have a good basic awareness of the major sustainability crises, they also have some advanced domain-specific awareness.

One of the principal drivers for increased interest in sustainability issues up until this level seems to be the prominence of sustainability issues in mainstream media, and in particular the media presence of the Swedish climate activist Greta Thunberg, and the American green tech-entrepreneur Elon Musk as explained by **EE.2M** and **ME.2M**.

> ***EE.2M R3:*** *I think it's great to have someone with a network like Greta Thunberg has got now. The network she has built, the organisation around her, it moves something, especially when she… like, the Nordic Council, just refused to take an award, so in that way I think it's great.*

> ***ME.2M R2:*** *Maybe I'm listening too much to Elon Musk. He thinks we can solve all the world's problems by shooting rockets to Mars.*

The result is a good general knowledge base on the sustainability crisis, as an interest in finding out more. Interestingly, for some students, the presence of these "media heroes" generated paradoxical reactions, on the one hand getting them more interested in the subject, but on the other leading them to vehemently disagree with the solutions offered by these public figures, as exemplified by **BEM.2M** and **EE.3M**:

> ***BEM.2M R3***: [*Me and my fellow students] are more likely to do their own research or express motives or incentives on the basis of actual peer reviewed articles, rather than sources or information through these propagandist "nonviolent civil disobedience" environmental movements "Extinction Rebellion", "Greenpeace" or Danish "Den Grønne Studenterbevægelse".*

It should be noted that this student disliked the sustainability attitude and modes of engagement of BEM students so much that he switched to the environmental sciences programme instead after P2, and these new classmates are who he refers to when he refers to his "fellow students".

> ***EE.3M R3:*** *I thought a lot about people like Greta Thunberg and Alexandra Ocasio-Cortez, that came up with the Green New Deal, and I don't agree with their approaches. I do believe in climate change and it's an important issue but the way they do it, I simply don't agree… I still have hope that we can find a technological solution.*

In this category, there is also specific, in depth knowledge and interest in one or several particular domains. Usually, this specific interest appears to be triggered by an interesting PBL project on a relevant sustainability subject, or a class on sustainability within the curriculum, a situation encountered by **ME.1M** and**ML.2F**.

> ***ME.1M R3****: We had a lot on the mechanical properties of plastics, we had a lot on microplastics - the lecture definitely was an eye opener for me. I'm definitely thinking about it more than I used to.*

> ***ML.2F R3:*** *In the 2nd semester we had the options of working with exercise or food waste, and I was very excited about working with food waste and I actually got to do that and that sparked an interest in how I could continue to work with these things.*

4.4 Category 4: high interest, advanced "systemic" awareness

The fourth category covers students who are actively interested in sustainability issues, and actively try to integrate these issues in their studies and as part of their lives – this relates to the competences identified in the literature review (Riekman, 2017). These students show a good understanding of the scale and scope of sustainability problems, and have both broad and deep awareness of major sustainability problems. It could be said that they have a "systemic" awareness because they are aware of the systemic problems that cause systemic sustainability issues. Almost all the students who have this level of interest and awareness were already interested and aware at the start of their degree programme, but pushed it further during their degree programme. This level of awareness correlated strongly, but not always, with political engagement, as we shall see.

> ***ML.1M R3:*** *I've realised how much of a huge deal it is, it's bigger than all of us…. When I saw how close we are, that we have a deadline, by 2040, we need to change. And that kind of woke me up, like, yeah, this is really messed up. We're killing ourselves! We need to change quick.*

> ***BEM.3F R2****: There still needs a lot of things being done with sustainability… there's a lot of individual people, or small groups, especially with plastic or with how you need to stop using plastic straws or something, there's a lot of small, individual groups of people saying – "this is bad", or making reusable straws, or, yeah, a lot of small groups doing that, but it's not only the plastic straws that need to be dealt with, it's the whole plastic industry.*

The systemic awareness was most prominent in the BEM group, and BEM.5F credited the study programme for this:

> ***BEM.5F R2:*** *I think there's a lot in my personal life, but also, I think also the studies because you read about all these things that are being done and the possibilities on what more can be done, and that motivates you.*

But there was most probably also a selection-bias at the start of the programme, as we know that students who are already aware and interested in sustainability are much more likely to opt for environmentally-oriented studies, as described by Prevot, Clayton and Mathevet (2016).

5 Discussion

In terms of the evolution of the responses over time, we see clearly in Figure 1 that the classical engineering students and the medialogy students start at a different level of awareness and interest than the BEM students, which can be attributed to the above-mentioned selection bias. We see an increase in awareness in the vast majority of students between R1 and R3, regardless of their starting position. Four students did not change their awareness and interest levels.

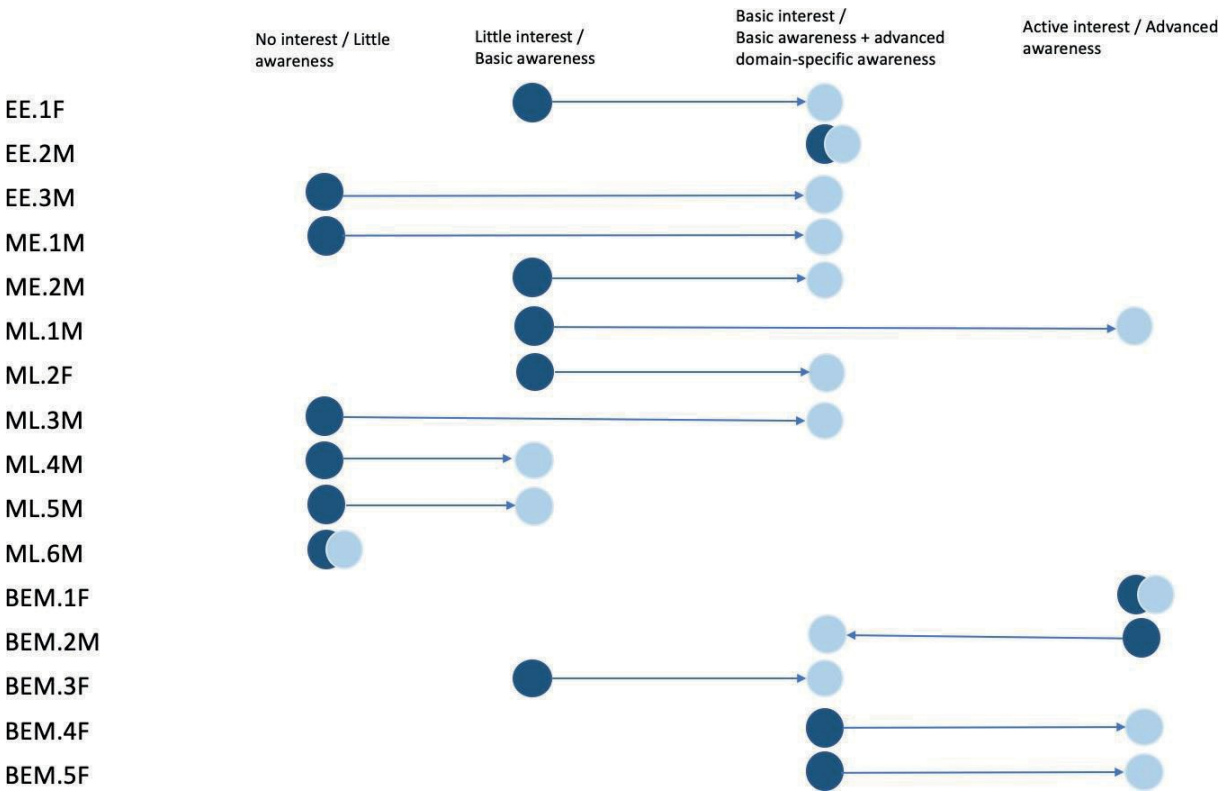

Figure 1. Evolution of sustainability interest and awareness between R1 and R3

We can propose the following explanations for the exceptions:

- ML.6M is truly afraid to delve into the subject and lives by his motto than “ignorance is bliss”. His own powerlessness in the face of the sustainability crisis terrifies him and he would rather not know at all, than knowing, and then needing time to build up sustainability competences to address his anxiety.
- EE.2M was already fairly aware of the situation, but any further interest was limited by personal mental health struggles, and he found the subject too depressing to go further.
- BEM.1F she was already extremely aware and involved at the start of the programme, and while her engagement levels changed (she joined Extinction Rebellion), her awareness and interest remained high.
- Student BEM.2M became less systemically aware of the situation, going from a situation of systemic awareness and interest, to one in which he only focused on one specific domain, namely energy, and

only from the standpoint of theoretical physics. This could be explained by his negative interactions with his BEM project group, prompting him to leave the BEM programme altogether.

The overall shift in awareness and interest seems to have two main causes, as mentioned above:

- firstly, the increased media attention given to sustainability issues, particularly in the wake of actions by Greta Thunberg, Extinction Rebellion, and Elon Musk, among other "big names" in the sustainability debate. This is in line with what has been called in the mainstream media a "Greta-effect" (Nevett, 2019), according to which the Fridays for Future movement led by the Swedish teenager has spurred a world-wide increase in awareness and interest in sustainability among young people.
- Secondly, the introduction of sustainability issues within the courses and projects. It was however no clear whether the specific PBL project format had any advantage over regular lectures in introducing students to sustainability issues since both were mentioned by students as factors triggering interest. It may be, however, that the PBL format indirectly increases students' interest in global problems, and the "real world" nature of the project problems encourages domain-specific awareness. Thus, while the previous quantitative study and this qualitative study present circumstantial evidence for a "PBL-effect", it might be suggested that more fine-grained qualitative approaches such as case-study or diary studies, which include direct observation of the PBL work and in-the-moment reflection would provide further insights that post-hoc qualitative interviews.

While our results show that an increase in sustainability awareness and interest is *likely* in a PBL environment, it is not guaranteed. Therefore, we suggest that there is a need for both targeted and systematic initiatives to increase the impact of education for sustainability in the curriculum for all students, even those that might be less susceptible to the methods currently employed. To do this, the project format is a promising format, but should be reviewed and improved in the light of emergent EESD innovations – for instance project types have emerged to promote a comprehensive systemic approach: so-called "mega projects", that have the ambition of engaging several student groups from different disciplines to address wicked sustainability problems.

6 Conclusion

This qualitative study presented further evidence to support the argument that engineering students in systemic PBL universities are likely to increase their awareness and interest in sustainability issues over the course of their degree programme. This seems to be the case across very different engineering disciplines, adding further evidence to the argument that this is not a phenomenon only confined to "environmental" engineering studies, but perhaps related to the PBL process itself as students orient themselves in the world outside academia through their projects. However, the precise effect of the PBL was not widely apparent from the interviews, and therefore it will remain as an argued hypothesis that project work adds sustainability awareness and interest via the problems analysed by the students within academic knowledge domains. Further research to investigate this could include diary studies during project work and field work observations of project work.

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